QUANTITATIVE MEASUREMENT OF INDUSTRIAL RISKS IN DISTRIBUTION NETWORKS

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ABSTRACT

Utilities are subject to diverse risk categories as, for instance, market risks, credit risks, financial risks, regulatory risk, industrial and environmental risks. In order to reduce its risk exposure, Enel Group analyses and monitors risks in all the above mentioned areas. From an organizational point of view, Enel Group has recently constituted a Risk Management Department at Holding level, which is in charge of identifying, assessing and monitoring Group's risks with the aim of minimizing its exposure and impact at Holding, Division and Country level. Within the Risk Management Department of the Enel Group, Industrial and Environmental Risk Management Unit has developed and is now progressively implementing an integrated Risk Management framework that provides a quantitative measure of the industrial and environmental risk exposure of its assets and industrial activities worldwide.

INTRODUCTION

Industrial and Environmental Risk Management models cover all the Enel Group business activities (Upstream Gas, Generation, Distribution and Market) through all their processes (Business Development, EPC, Operation and Maintenance and Decommissioning) assuring a proper and homogeneous risk assessment and measurement of each single plant/project and also allowing to aggregate results in order to provide the industrial risk exposure of each Country/Company/Business activity and of the Enel Group at consolidated level.

Besides the risk assessment and measurement, the Industrial and Environmental Risk Management Unit also performs "what if" analysis in order to measure the change in risk profile due to modification of risk factors and operating conditions; in addition, the developed tool allows Enel Group to measure and compare the efficacy of mitigation strategies and the extent of their efficiency in terms of cost/risk reduction.

The results of the analysis will be the basis for the development of industrial strategies aimed at ensuring Group industrial value protection also by measuring the possible impact of industrial risks on Enel EBITDA.

The paper describes the risk management framework and methodology particularly focusing on its application to distribution business and operation and maintenance processes. As an example, results of Industrial risk assessment on a pilot area of the Enel Group distribution network are presented.

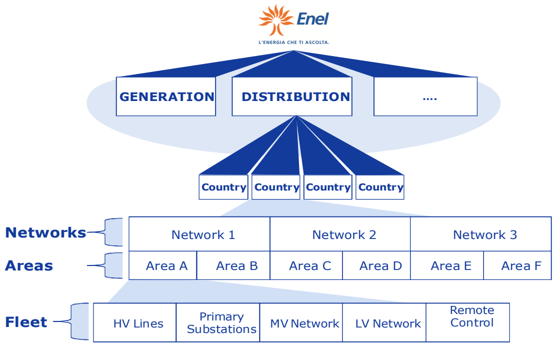

Figure 1: Schematic representation of the Company

INDUSTRIAL RISK METHODOLOGY AND METRICS

Risk management activities are carried out using an integrated system (IERMIS) and on a stochastic basis starting from the analysis of probability distribution of historical loss events. In addition, other tools like risk maps, Risk Owner Opinion, Risk Expert Opinion, integrate historical data to provide a perspective view on risks that historical data may not reveal and to evaluate the possible impact of unexpected disruption events. Industrial Risks are evaluated in terms both of direct and indirect losses. Direct losses are evaluated in terms of cost for reparation/substitution of fault components, while indirect losses are assessed in terms of SAIDI, SAIFI, HV and MV customers interruptions and very long outages in order to verify the compliance with the regulators targets, their effect on the premium/penalty/compensation system and to identify critical areas. The risk assessment covers both ordinary risks (direct costs and interruptions due to ordinary faults or ordinary bad weather conditions) and extraordinary risks thus assessing the probability of occurrence and the possible impacts of strategic components faults and extreme natural events (for instance very bad storms, earthquakes, etc.) and identifying the most critical assets/network areas and their vulnerability to different risk factors.

Industrial Risk Mapping

Industrial Risk Mapping (in case of Distribution, Network Mapping) represents the first step of the process with the aim of modelling the Network area in the industrial risk system.

Network Mapping identifies all the assets and their connections in the network area in terms of single HV lines, Primary Substations, MV lines, LV networks at municipality level and Remote Control Network.

Loss Data Collection

Loss Data Collection phase (LDC) represents the basis of the whole Industrial Risk assessment process.
During this phase, direct and indirect industrial loss events (up to 15.000 records per Network Area per year for a single KPI) are automatically processed from Company databases by IERMIS which assigns frequency and severity probability distributions to each asset identified in the Network mapping process and to the Network area itself (probability distributions are defined for each of the KPIs assessed).

Risk Owner Opinion

The Risk Owner Opinion phase (ROO) has been established in order to integrate the historical information with information provided by Risk Owners (Network area management and operative staff, network operation staff, network development staff). Among others, during the interviews the following aspects are assessed: recent investments or planned investments, significant variations in ordinary maintenance procedures, load increase, increase of distributed generation in the area, variation in the quality of materials, variation in the number of employees and workers, etc.
IERMIS automatically associates corrective coefficient to the information provided by the Owner that modify frequency and severity probability distributions' parameters (mean and standard deviation).

Risk Expert Opinion

Risk Expert Opinion phase (REO) represents the richest part of the whole process, since it allows to assess and quantify the vulnerability of the Network Area and of its assets to extreme events which have probably never occurred (High Impact Low Probability HILP) both in terms of high impact faults on strategic components of the network and of extreme natural events which could hit the area.

Technical events REO assessment

This part of the REO assessment is devoted to the probabilistic analysis of high impact faults which could occur to strategic components of HV lines (mainly radial ones) and of Primary Substations.
In the following the main characteristics of the model related to Primary Substations are described.
The model takes into account several input parameters, among others: plant configuration, installed power, number of LV customers supplied, number and installed power of HV and MV customers, number and power of distributed generation plants connected to the primary substation, remote control systems presence and efficiency, percentage of supply that can be restored from a second transformer and from the MV network, distance of the primary substation from the nearest workers operating centre, potential implication of other plants in case of fault in the primary substation, technology of installed components, number of mechanical operations of circuit breakers and switches, transformers load factor, circuit breakers switches and protection systems efficiency, etc.
Basing on international benchmarks on major failures failure rates of primary substations components and on all the relevant input data, the best frequency distribution is determined for high impact faults which could affect every strategic component in the primary substation.
Performing a Fault Tree Analysis on the main bays and components of the Primary Substation and taking into account the input data representing a picture of the particular plant, severity distributions are determined for all the KPIs assessed. By running Monte Carlo simulations the probability distribution representing the vulnerability of the Primary Substation to HILP faults can be determined.

Natural events REO assessment

Industrial risk assessment of extreme natural events is performed by analyzing the combination of hazard level and assets vulnerability in the considered area.
For the distribution network assessment the following risk factors have been considered: extreme weather risk (wind, snow, ice), hydrogeological risk (geotechnical collapse, landslides, floods), seismic risk.
Extreme natural events hazard level in the considered area is determined through a probabilistic analysis by assessing the meteorological and seismic maps of the region: a curve reporting the frequency of occurrence and the related intensity level is associated to each of the considered extreme natural events.
Vulnerability is defined as the aptitude of network assets in being affected by damages of diverse extent in case of occurrence of diverse intensities natural events and is determined by taking into account several input parameters, among others: asset age, general conditions, level of maintenance, construction materials, etc.
By combining the extreme natural events hazard level and the vulnerability of the distribution network in the area, fragility curves are determined.
For each of the considered natural events the fragility curves associate a frequency of occurrence to the related minimum, most likely and maximum damage which could occur to the particular asset considered.
Risk exposure is expressed both in terms of direct losses and of indirect losses (assets unavailability period).

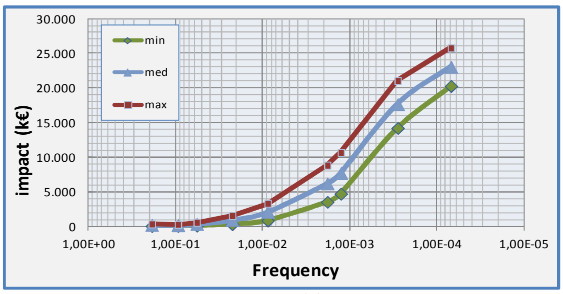

Figure 1 – Example of fragility curves

Industrial Risk calculation model

The aim of the model is to estimate risk exposure, in terms of Expected Loss (the most likely value of the probability distribution representing the industrial loss) and Value at Risk (the maximum loss in a defined time horizon with a certain level of confidence), for all KPIs, based not only on historical data, but also integrating ROO and REO analysis in order to provide a complete and exhaustive risk measure of the Network Area.

Risk measures are calculated through Monte Carlo simulation combining frequency and severity distribution at single asset level, then aggregating them to provide risk exposure of the whole Network Area. This allows to prioritize risks, to compare homogeneous assets of different Divisions/Countries of the Enel Group and select priorities in mitigation plans management.

RESULTS FOR A PILOT AREA OF THE ENEL GROUP DISTRIBUTION NETWORK

Some examples of the industrial risk assessment results for a network area of the Enel Group distribution network (Network Area A) are showed and the impact of regulatory framework on the EBITDA of the related distribution company is assessed. Network Area A main characteristics are indicated in table 1.

Network Area		A
Territory	(km^2)	7.654
110 kV lines	(km)	420
Primary Substations	(n)	17
20-6 kV lines	(km)	2.960
MV/LV substations	(n)	545
Pole mounted transformers	(n)	1.450
LV lines	(km)	7.000
LV customers	(n)	210.000
HV-MV customers	(n)	448

Table 1 – Technical characteristics of Network Area A

As an example, in figure 2 statistical distribution of Network Area A direct losses is presented.

In tables from 2 to 4 Expected Loss and VaR 95%, 99% and 99,9% (over a one year period) of direct losses, SAIDI and SAIFI are presented both at Network Area level and fleet of homogeneous assets level.

In figure 3 an example of drill down analysis is presented (Network Area A, Primary Substations, SAIDI, VaR 95%); results for each HV line, Primary Substation, MV line or LV municipality at every percentile and for all the KPIs are available.

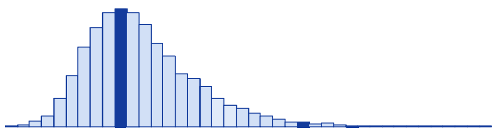

Figure 2 – Statistical distribution of Network Area A direct losses

DIRECT LOSSES (k€)	EL	VaR 95	VaR 99	VaR 99,9
Network Area A	**1.241**	**1.680**	**1.899**	**2.239**
HV lines	4	14	54	132
Primary Substations	38	414	549	772
MV Network	230	296	338	403
LV Network	966	1.191	1.358	1.717
Remote Control Network	3	7	13	24

Table 2 – Network Area A direct losses results

SAIDI (min./cust.)	EL	VaR 95	VaR 99	VaR 99,9
Network Area A	**252,0**	**304,9**	**326,9**	**360,2**
HV lines	3,1	19,6	37,6	60,5
Primary Substations	11,7	45,4	62,2	82,4
MV Network	170,5	201,9	217,9	241,6
LV Network	66,6	74,6	78,7	84,2

Table 3 – Network Area A SAIDI results

SAIFI (int./cust.)	EL	VaR 95	VaR 99	VaR 99,9
Network Area A	**6,32**	**7,17**	**7,48**	**7,84**
HV lines	0,20	0,43	0,54	0,68
Primary Substations	0,47	0,99	1,16	1,40
MV Network	4,86	5,40	5,65	5,91
LV Network	0,78	0,94	1,03	1,12

Table 4 – Network Area A SAIFI results

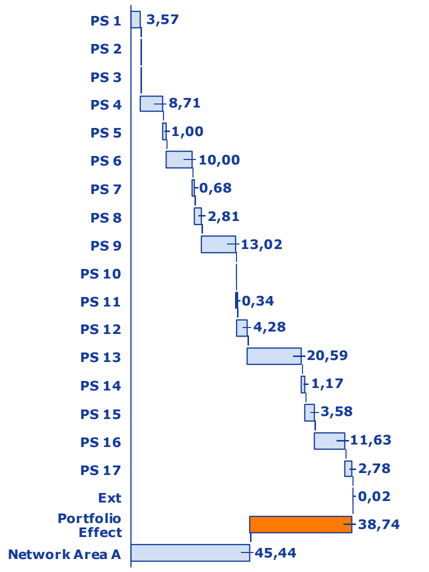

Figure 3 – SAIDI (VAR 95%) for Network Area A Primary Substations

Industrial risk has been measured in the as-is situation and also simulating three different investment plans, thus assessing the sensitivity of each different plan. Diverse mitigation typologies have been considered: meshing of part of the HV grid, erection of new Primary Substations, substitution of components in Primary substations, erection of new MV lines, substitution of components or conductors in MV lines, substitution of overhead bare conductors with cables in both MV and LV network, remote control implementation, extraordinary maintenance program, changes in the organizational procedures, etc.

Risk models are capable of accepting a huge number of diverse mitigation actions as inputs; model settings are automatically updated and new Monte Carlo simulations are run in order to calculate the new risk profile of each single asset, of homogeneous assets groups and of the whole Network Area.
Costs of proposed mitigation scenarios and their effects on the monitored KPIs are indicated in figure 4.

AS IS			SCENARIO 1 21,2 M€	SCENARIO 2 7,8 M€	SCENARIO 3 5,4 M€
Direct losses (k€)	EL	1.241	1.176	1.202	1.226
	VaR 95	1.680	1.524	1.562	1.620
	VaR 99	1.900	1.729	1.762	1.838
	VaR 99,9	2.239	1.999	2.043	2.120
SAIDI (min/cust)	EL	251,96	213,82	226,49	224,73
	VaR 95	304,88	254,34	269,45	271,78
	VaR 99	326,94	270,33	288,26	289,59
	VaR 99,9	360,16	290,02	312,81	319,66
SAIFI (int/cust)	EL	6,32	5,38	5,74	5,74
	VaR 95	7,17	6,04	6,47	6,53
	VaR 99	7,48	6,30	6,75	6,79
	VaR 99,9	7,84	6,55	7,08	7,09
Interruptions HV MV (kW)	EL	575.469	535.075	539.914	544.596
	VaR 95	710.371	640.318	656.167	671.151
	VaR 99	756.374	680.137	703.453	717.042
	VaR 99,9	809.369	728.493	752.580	764.542
Very long outages (Cust.*h/targ)	EL	9.742	8.570	8.631	8.651
	VaR 95	30.984	20.812	24.919	25.812
	VaR 99	44.329	29.201	38.132	38.856
	VaR 99,9	59.400	42.661	53.274	55.418

Figure 4 – Mitigation analysis of Network Area A

Furthermore the impact of a regulatory framework based on incentives/penalties scheme on power quality has been assessed in terms of variability of distribution company EBITDA respect to the EBITDA of industrial plan (EBITDA@industrial risk).
In table 5 EBITDA@industrial risk for the distribution company of Network Area A under the diverse scenarios conditions are indicated.

EBITDA@IRisk Company A	As is	Mit 1	Mit 2	Mit 3
VAR 99,9%	-11,2%	-6,1%	-9,3%	-10,5%
VAR 99%	-9,4%	-2,5%	-4,9%	-5,5%
VAR 95%	-6,7%	-0,3%	-1,6%	-2,2%
EL	+1,2%	+6,7%	+5,7%	+5,7%

Table 5 – Variation of EBITDA of Company A with respect to the Industrial Plan Value

HILP natural events assessment results

Network Area A has also been subject to an industrial risk assessment dedicated to the analysis of extreme natural events. In particular HV and MV lines have been assessed in terms of vulnerability to extreme weather events and Primary Substations have been assessed in terms of vulnerability to seismic and flooding phenomenon.
As an example, in figure 5 and 6 direct losses results for each HV line and Primary Substation of the area are reported. Aggregated results and normalized results (risk per km of line or risk per number of primary substations) are available.
Aggregation of results at Network Area level is made taking into account both single assets vulnerability and their functional and structural connections.
Therefore industrial risk has been assessed at single asset level and at Network Area level with a probabilistic model able to identify the most critical lines or substations in the network and to correlate the effects of the single asset unavailability on the whole network performance.

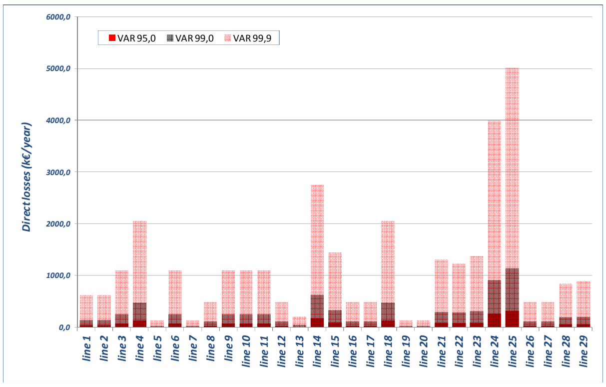

Figure 5 – Direct losses for HV line (Area A)

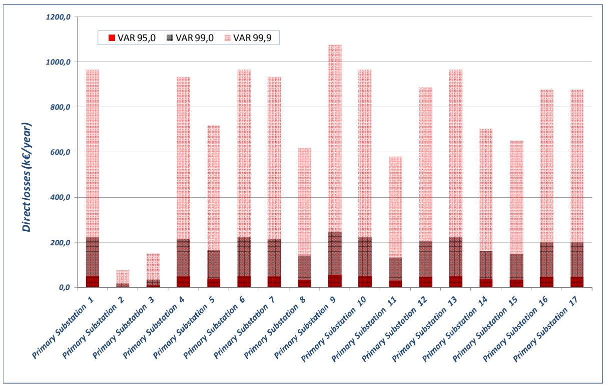

Figure 6 – Direct losses for Primary Substation (Area A)

CONCLUSIONS AND NEXT STEPS

Industrial and Environmental Risk Management model is able not only to measure risks, it is a day-by-day management tool. Indeed, it supports both distribution staff to manage the network, plan maintenance and raise awareness towards risks, both top management to better decisions that maximize return on investments.
Industrial and Environmental Risk Management Unit is now progressively implementing risk assessment in all Group's Countries where the distribution network is present, adapting the models at local regulatory frameworks; at the same time it is extending the models to measure industrial risk in all remaining phases of the process (business development, engineering procurement & construction, etc). The goal will be to measure industrial risk exposure of the whole Distribution Business Area and then to integrate it in the overall industrial and environmental risk exposure of the Enel Group.